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Netted Sensors

Site Security and Defense Situational Awareness

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

- Sensors and Situational Awareness
- Virtual Presence and Extended Defense (VPED)
  - System Concept Overview
  - Hardware Architecture
    - Multi-node architecture
    - Node/Sensor Description
      - Hybrid Networks
  - Algorithms
    - Multi-phenomena based detection
- Seismic Modeling
  - Application to algorithm development and sensor performance in varying environments
- Fusion and Communication for Ground and Air Sensors
  - Overview of fusion and communications integrated approach

Challenges for Fielded Systems

Real World is Complex and Difficult

- **Current Systems and Algorithms**
  - **Low target density, modest clutter environment**
  - **Detection and Classification on High SNR Targets**
  - **Little Data Sharing**
- **Real World Situations are More Complex**
  - **Lower SNR (Asymmetric) Targets, high clutter**
  - **High Confuser Density**
  - **Smaller Inter and Intra Class Separation**

Networked Sensing is part of the Solution Space

- **Persistent Sensing**
  - **Use behavior over time as attribute**
- **Heterogeneous Sensing**
  - **Multiple Phenomena**
  - **Combination of Signatures for unique ID**
- **Spatial Diversity – Multiple independent looks robust**
- **Supports Multi-Layer Data Fusion**

Sensor System Trade Space

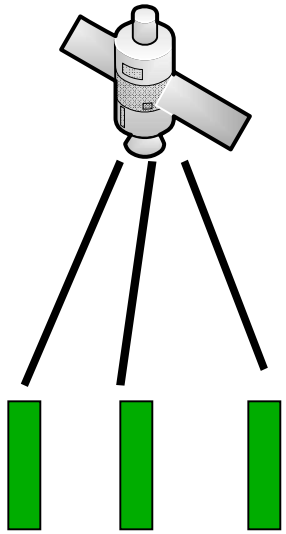
How Many? What type? How Capable?

Traditional Sensor Systems

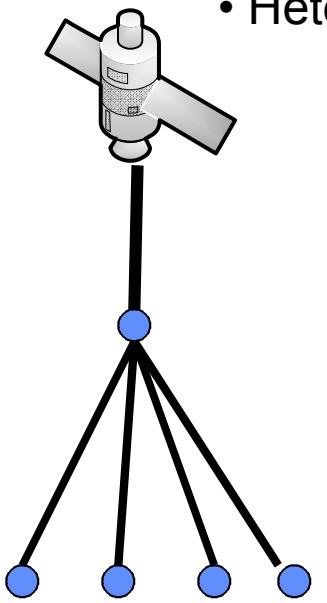
- Fewer, more capable nodes
- Localized data processing
  - Detection, Classification
  - CPA or Target bearing
- Multiple mode sensing
- Direct Comms to User

Networked Sensing

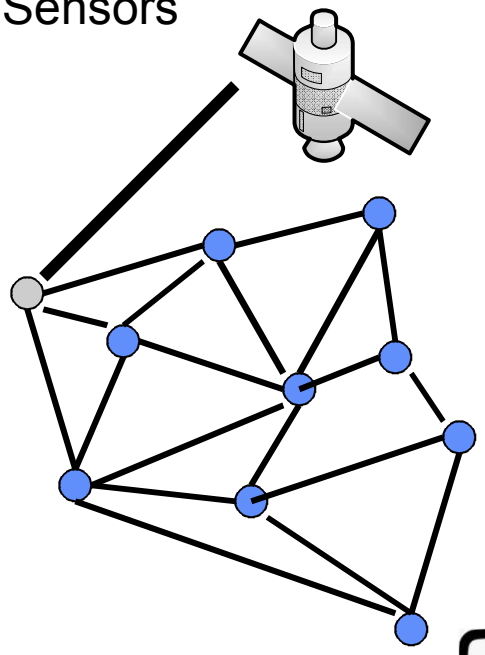
- Many Less Capable Nodes
- Peer to Peer Mesh Network
- Distributed Processing
- Distributed Control
- Communication rich
- Heterogeneous Sensors



Direct Connection



Tree Network



Mesh Network

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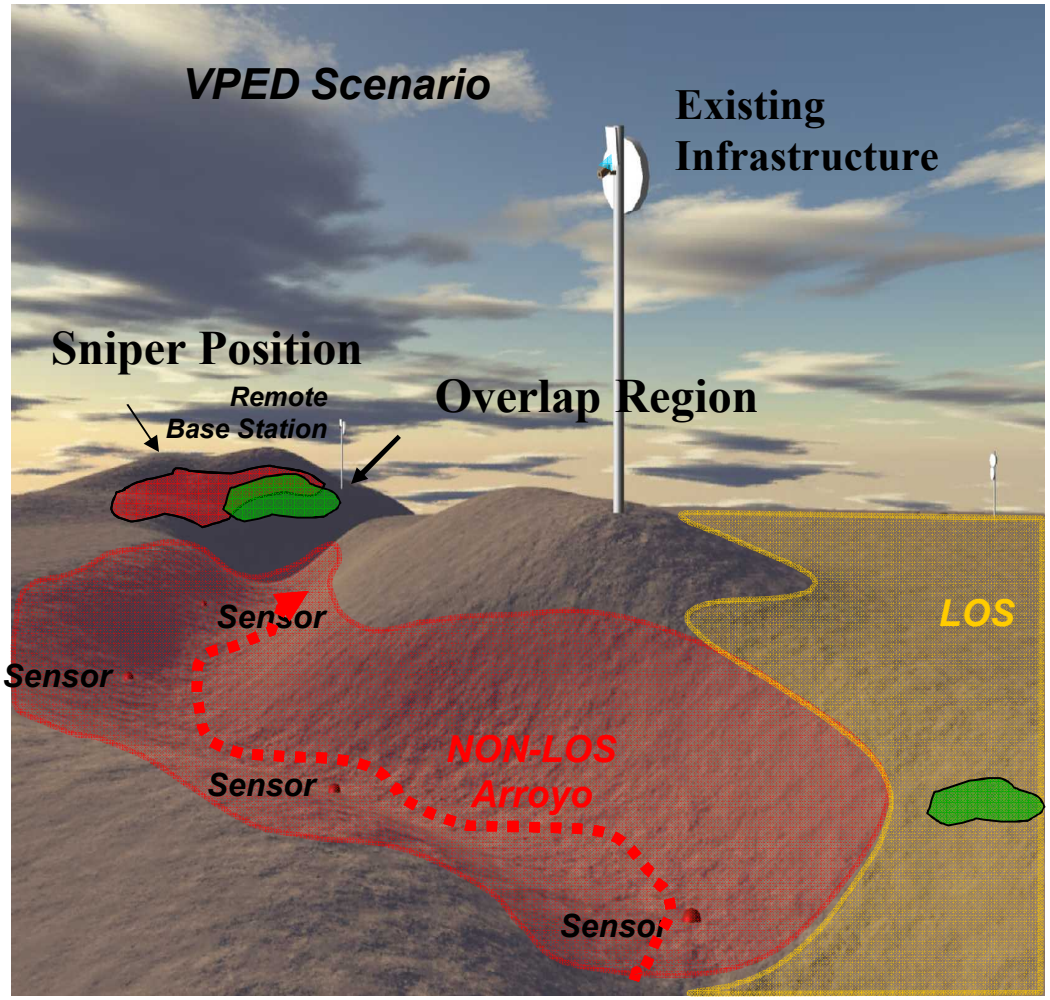
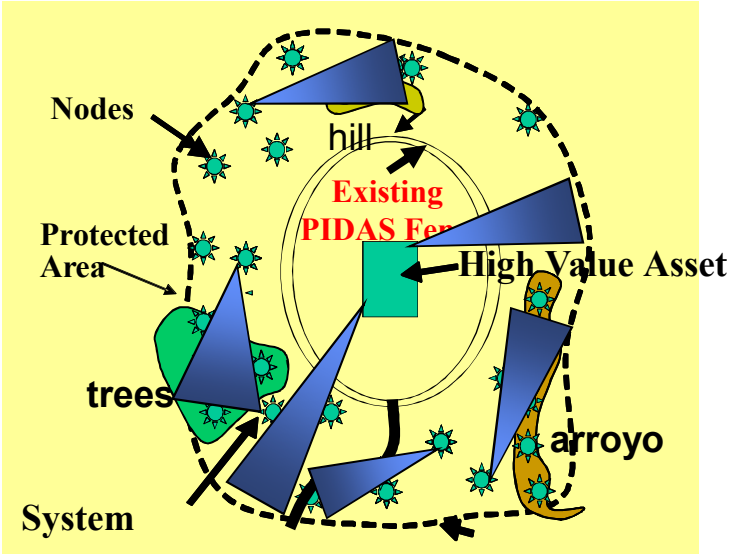
Virtual Perimeter and Extended Defenses Conceptual System





- Why use networked UGS?
  - Enhance non-line of site situational awareness
  - Increase force response time
- What are the core capabilities?
  - People – Detect, Classify, Localize & Track
  - Vehicles: Detect, Localize & Track
  - Preliminary Assessment
    - Images/Video
  - LOS Assisted Data Fusion
- Typical Transducers
  - Seismic, Acoustic, Magnetic, IR Imaging
- Integration with existing infrastructure
  - COTS: Trip/Threshold Sensing

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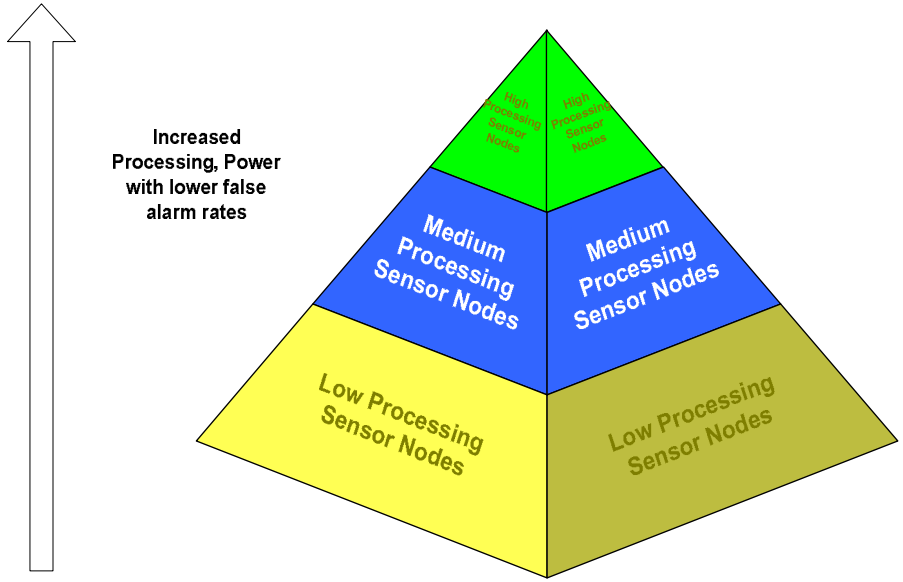
Sensor Network Architecture Elements

Layered Architecture



- **High Processing Node**
  - Decisions
    - Image/Signal Processing Algorithms
    - User Interaction
      - Near real-time
  - Communication
    - High Bandwidth
      - Real time Video
      - Real time acoustic/seismic data stream
- **Medium Processing Node**
  - Image and Signal Processing
  - Communication
    - High to medium bandwidth
    - Snap shot and video clips
- **Low Processing Node**
  - Signal processing algorithms
    - Simple Features
  - Communication
    - Low bandwidth

Metric: Cost per Area Coverage (CPAC)

Objective: Minimize CPAC

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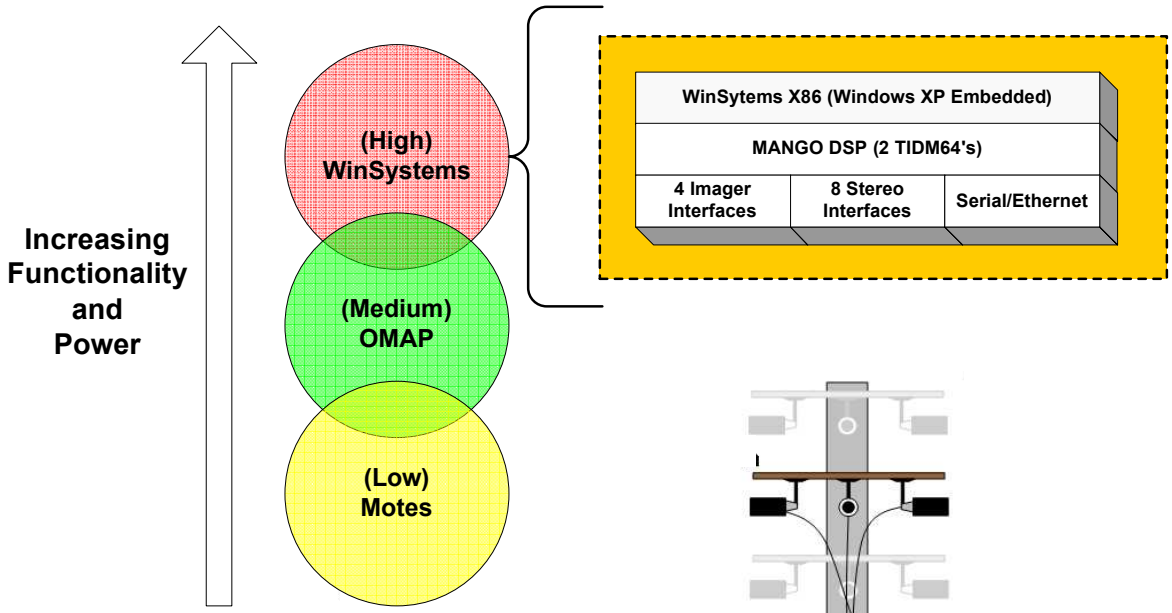
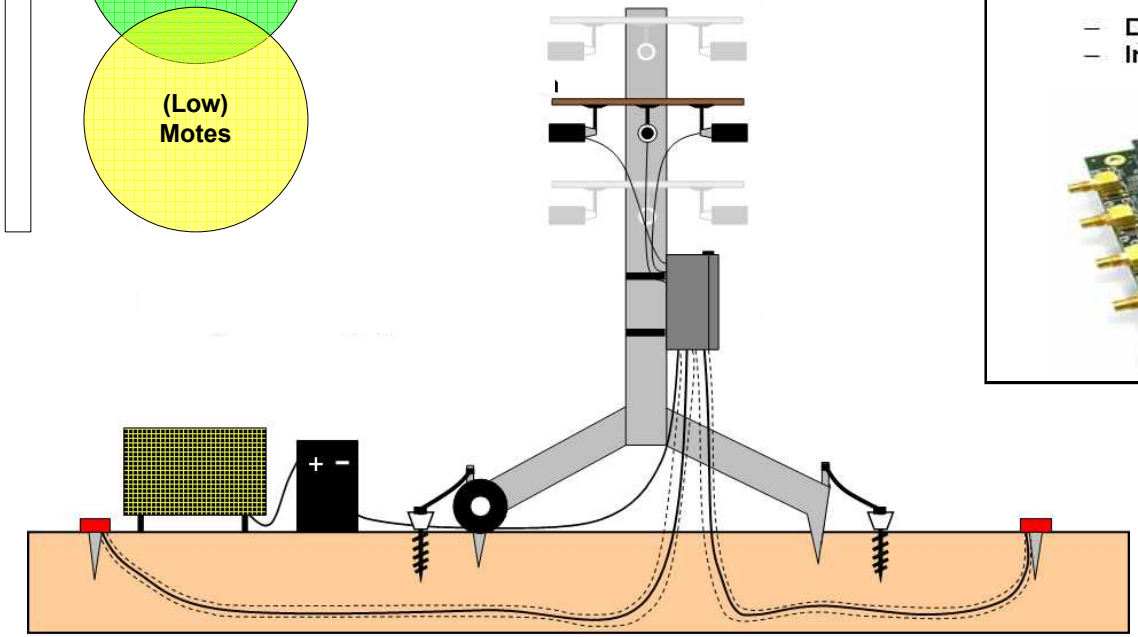
High Performance Processing Node



- Winsystems – Single Board Computer
  - Brains of the System
    - 366 MHz AMD Geode Processor
  - Data Storage
    - Compact Flash
    - USB drives
  - Communications Capabilities
    - Ethernet
    - Wireless 802.11 b/g
    - Radio Modems
- Mango – Digital Image Processing Board
  - Digitally Records Data
    - 4 Imaging Channels
    - 16 Analog Channels
  - Digital Signal Processing Algorithms
  - Image Processing Algorithms



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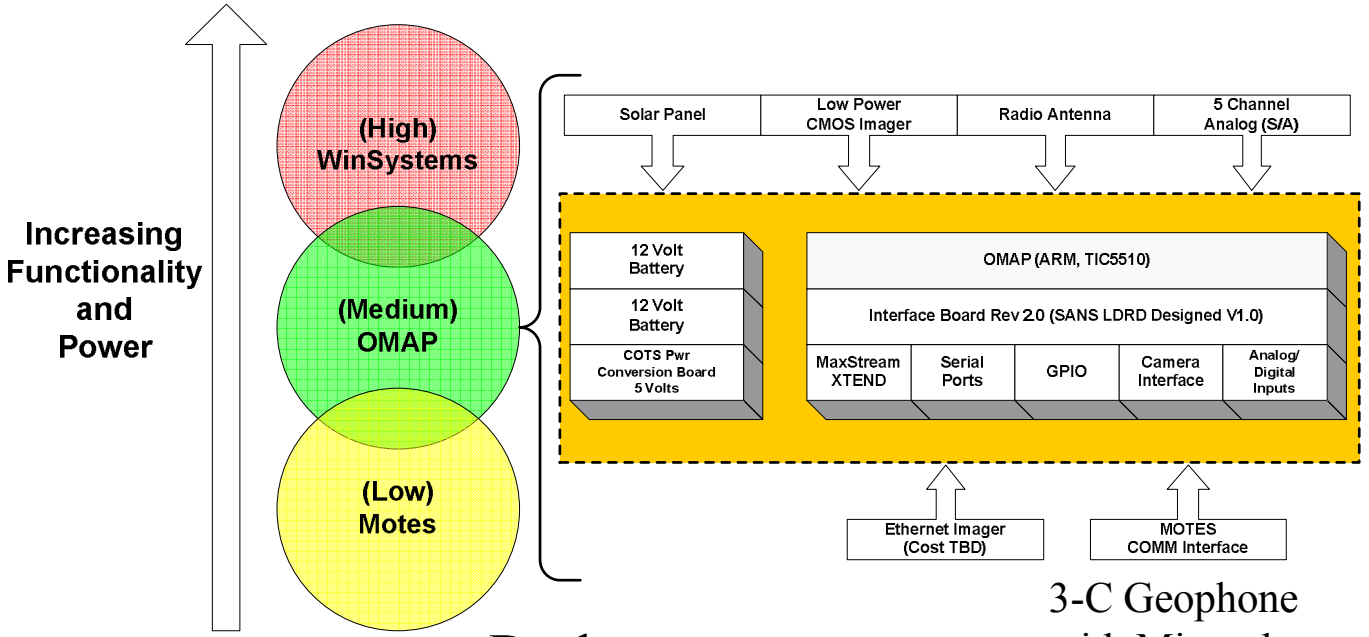
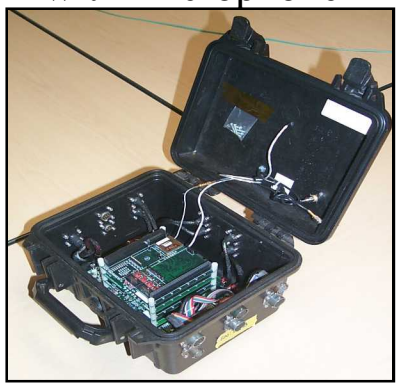
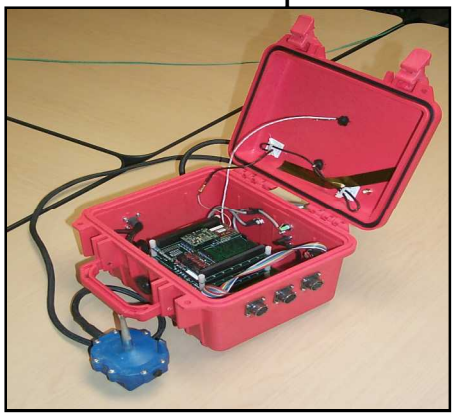
Medium Processing Node



Single Geophone with Microphone



3-C Geophone with Microphone



Deployment

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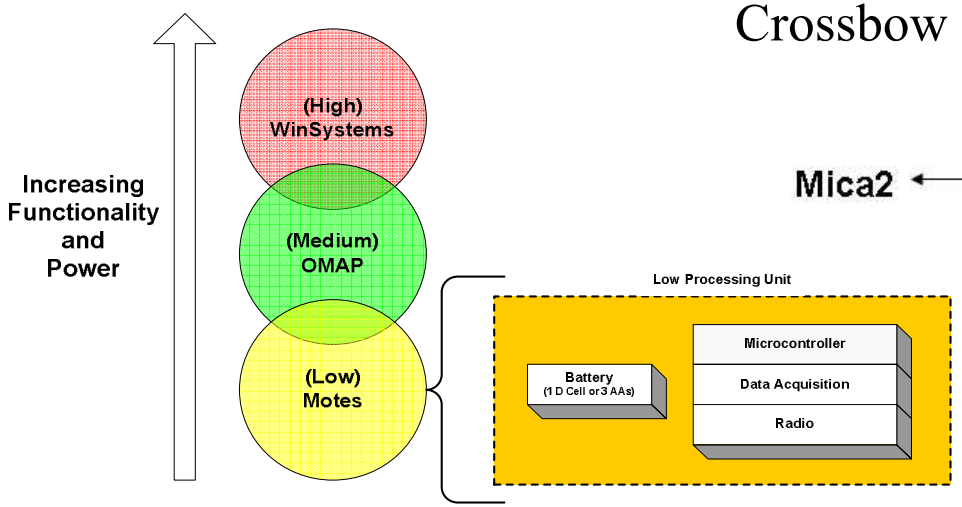
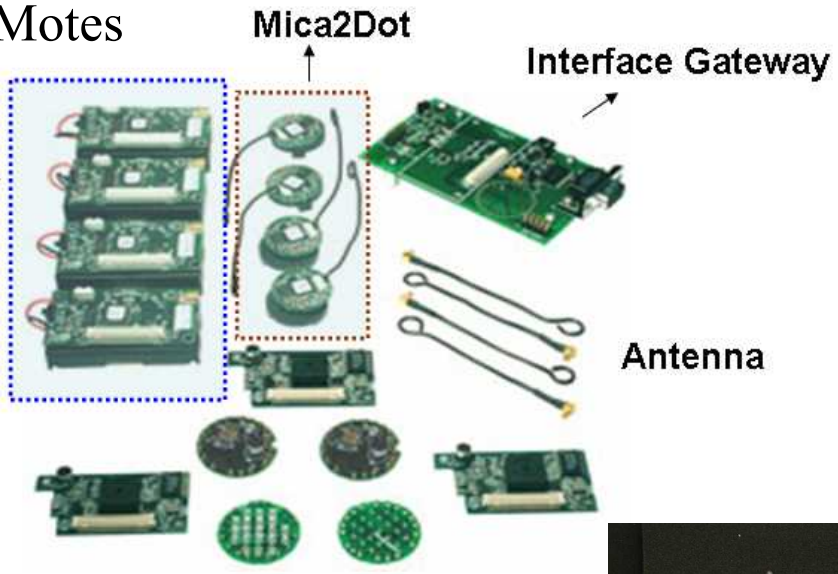
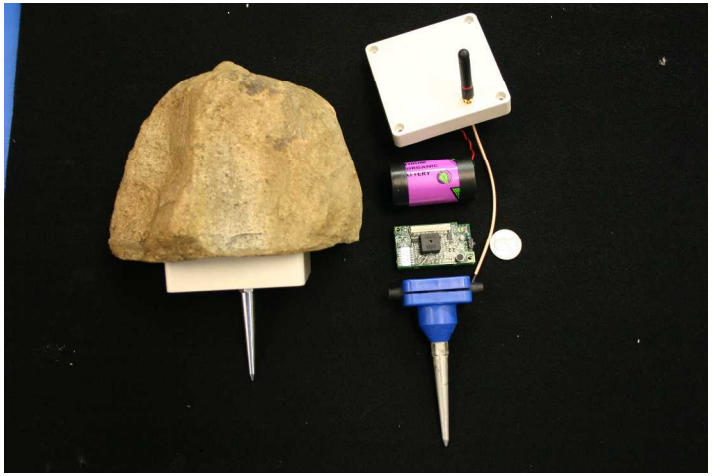
Low Processing Nodes



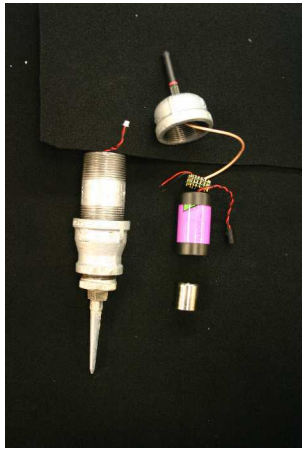
Crossbow Motes



Mica2 with Fake Rock Packaging



Mic2Dot



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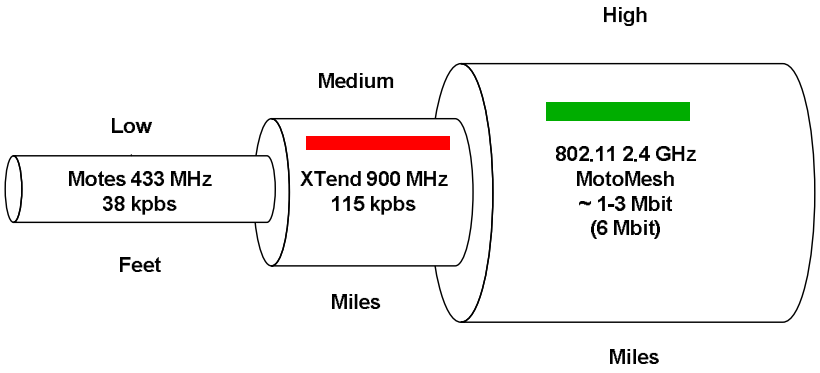
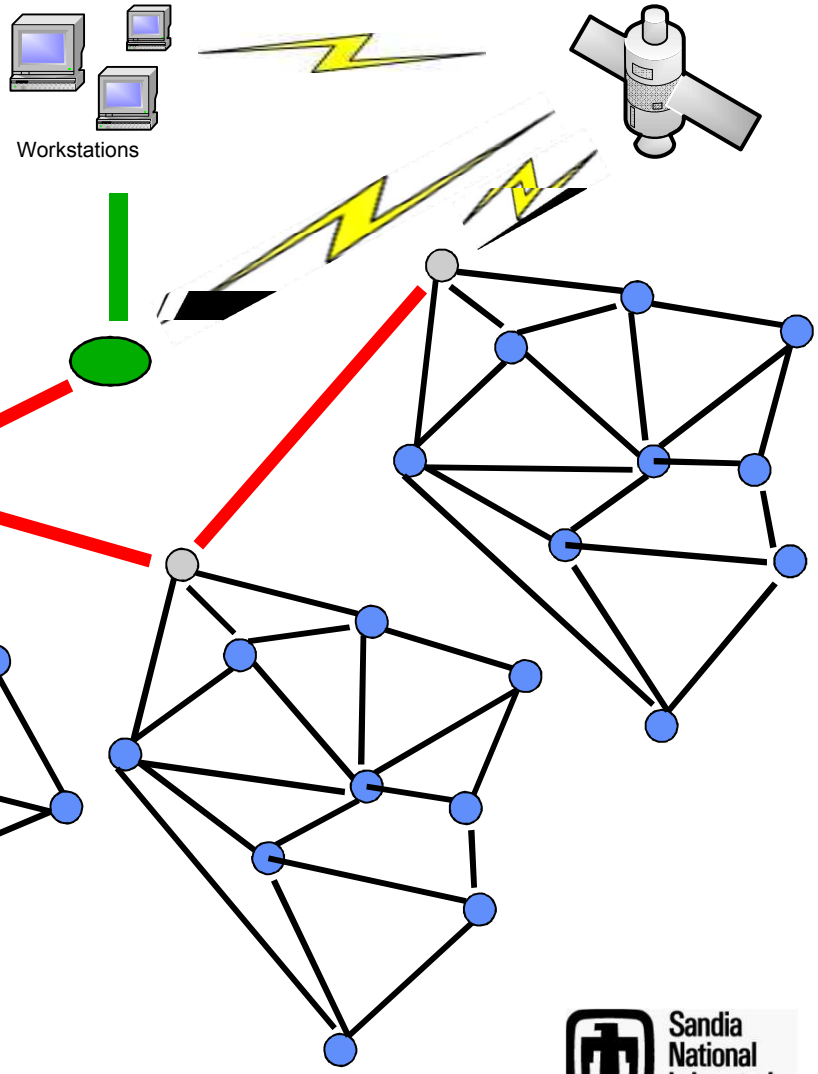
Hybrid Network Communication Network Structure Redrawn





Increasing Enrichment of Information Enabled by Hybrid Network

- High Processing Node
  - 802.11(MotoMesh)
  - SATCOM
  - MaxStream Xtend
- Medium Processing Node
  - MaxStream Xtend
  - Army Blue Radio
  - SATCOM
  - 802.11 (MotoMesh)
- Low Processing Node
  - Motes 433 MHz

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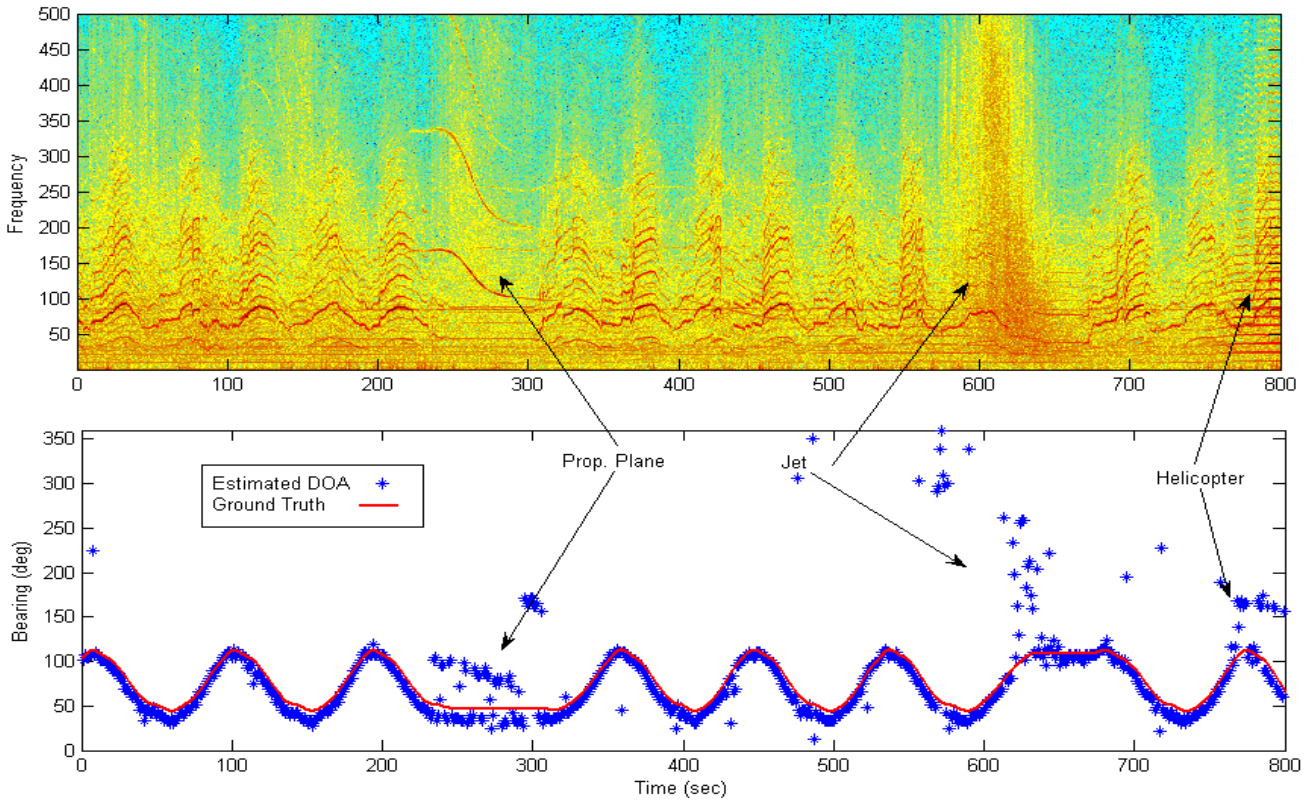
High Processing Node Algorithm (Example: Array Processing)

- **Beamforming and Tracking (Conventional)**
- **Use information in higher level fusion and reduction of false alarms**



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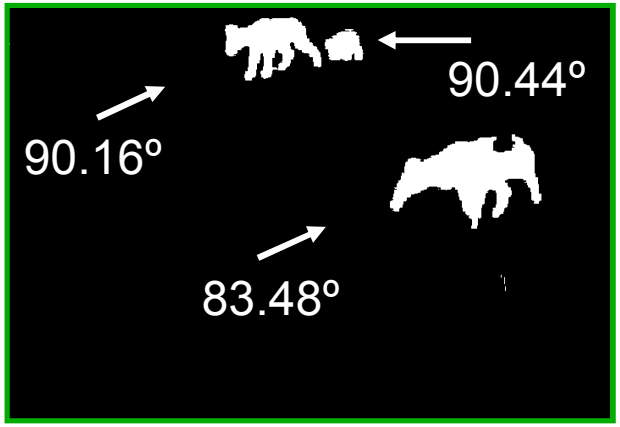
High Processing Node Algorithm Example: Automatic Animal Recognition

Human vs. Animal

- **Simple Rejection Features**
  - **Main Axis of Motion**
- **Advanced Evidential Reasoning**
  - **Integration of Statistics and Observations over time**

- determine background
- detect change
- normalize and subtract
- binarize
- extract feature and classify

Wolves



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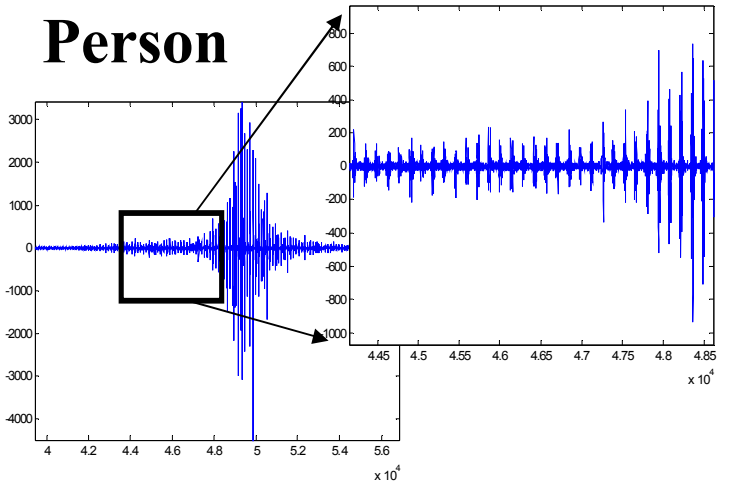
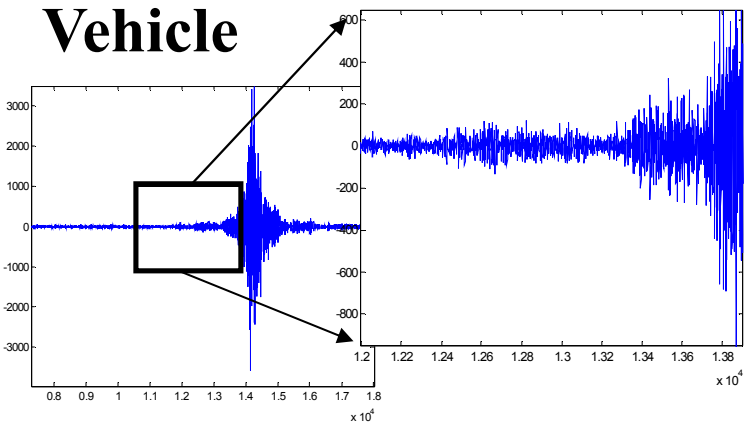
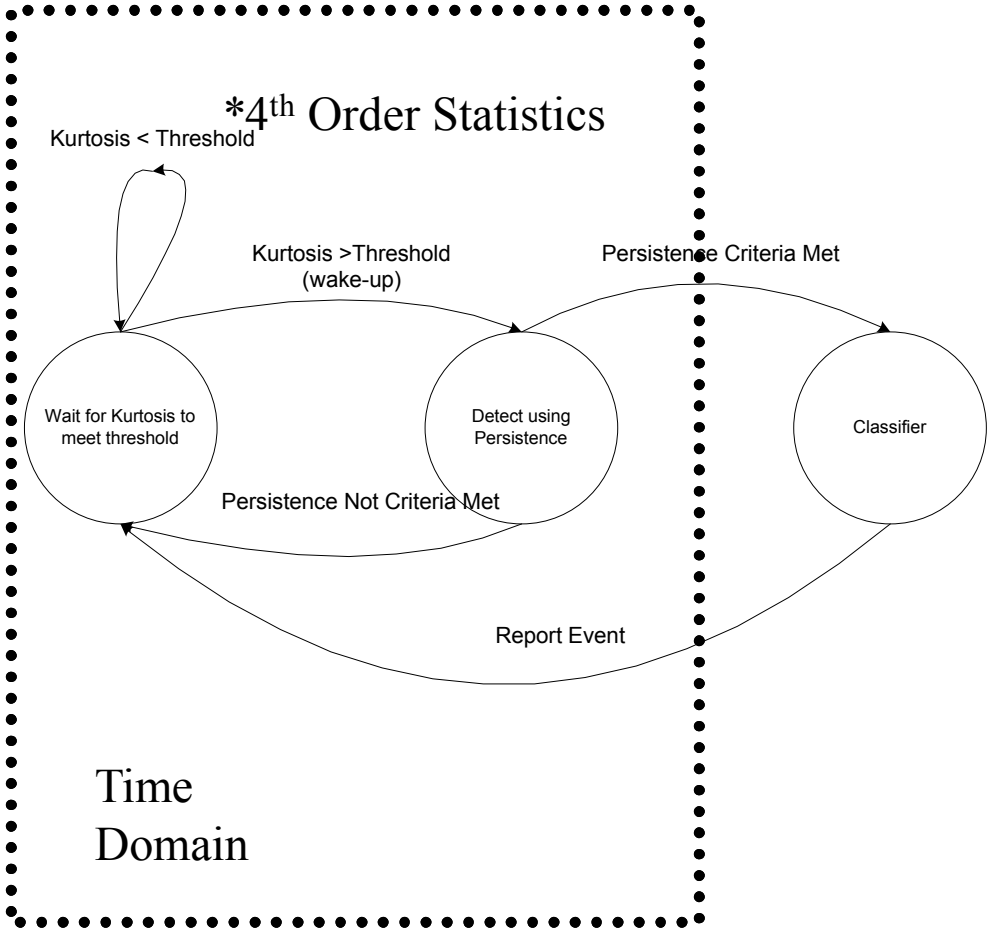
Medium Node Processing
Example: People Detection Algorithm
Kurtosis/Persistence/Rate (TD)







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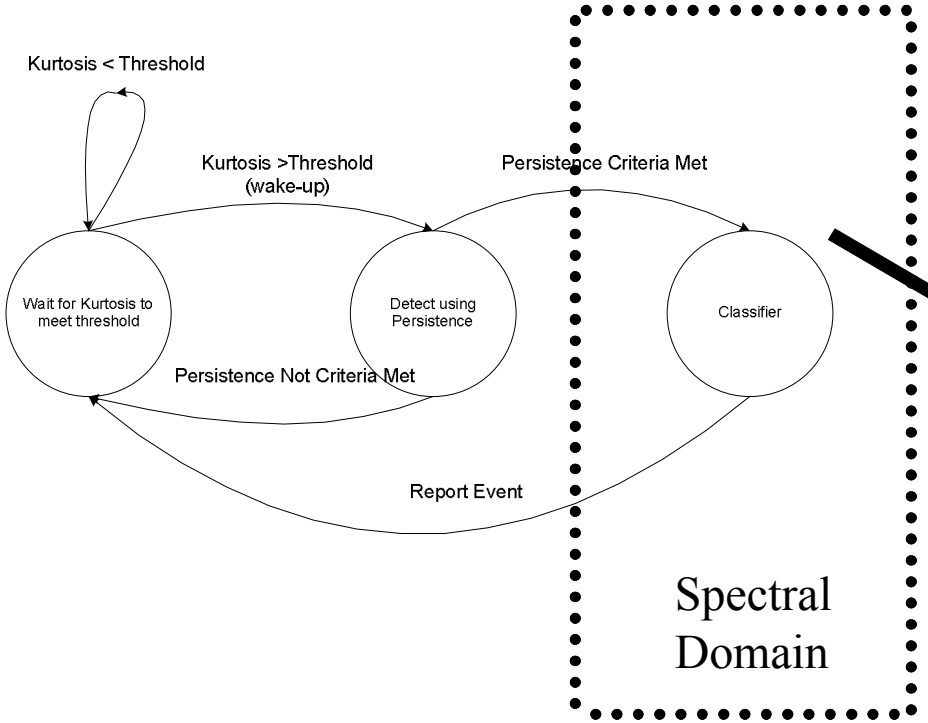
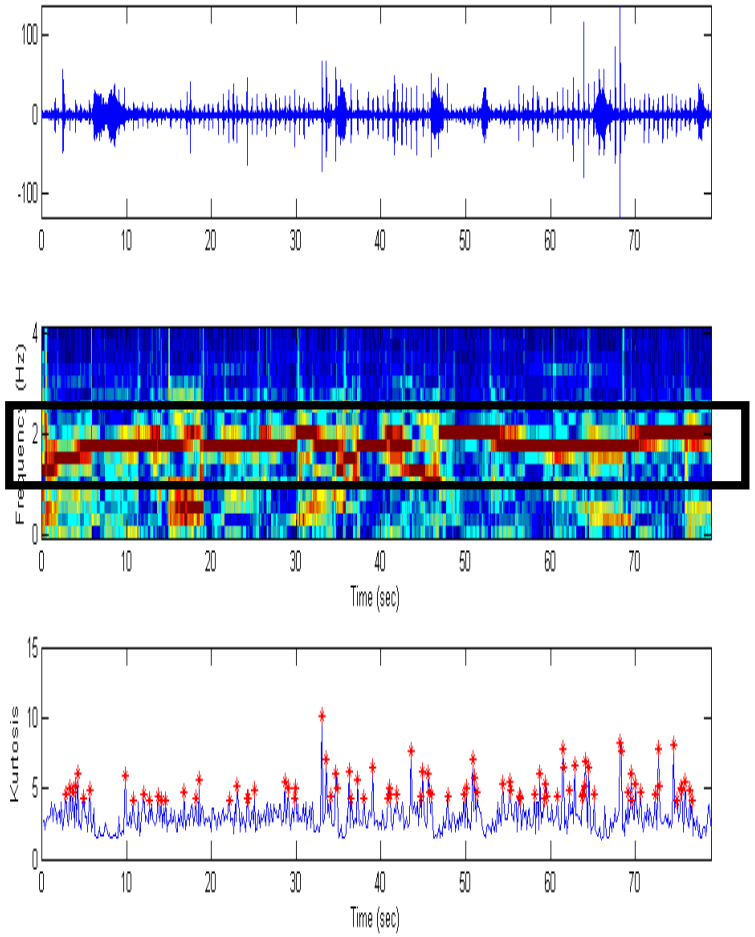
Medium Processing Node Classifier

*4th Order Statistics

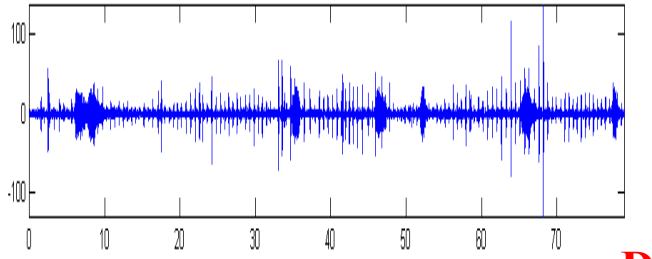


Person at 20 meters

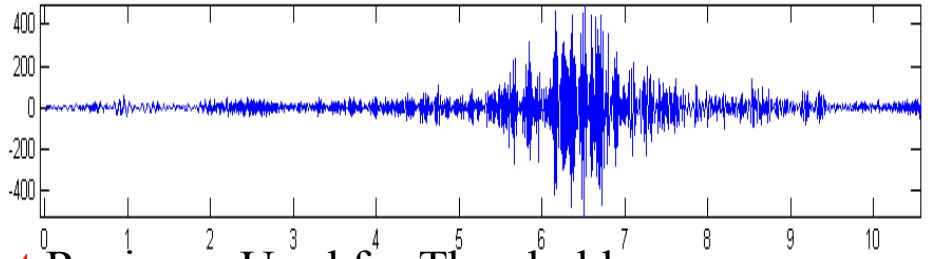


Target Comparison Vehicle

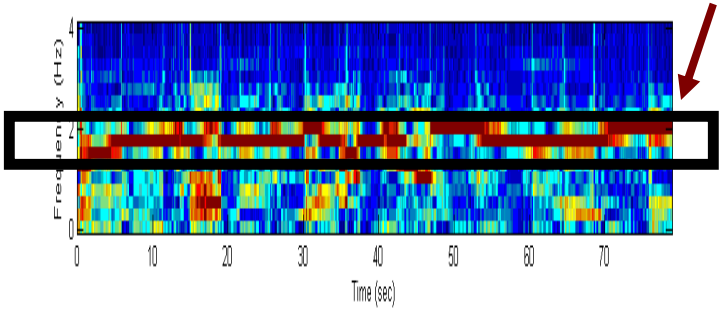
Person at 20 meters

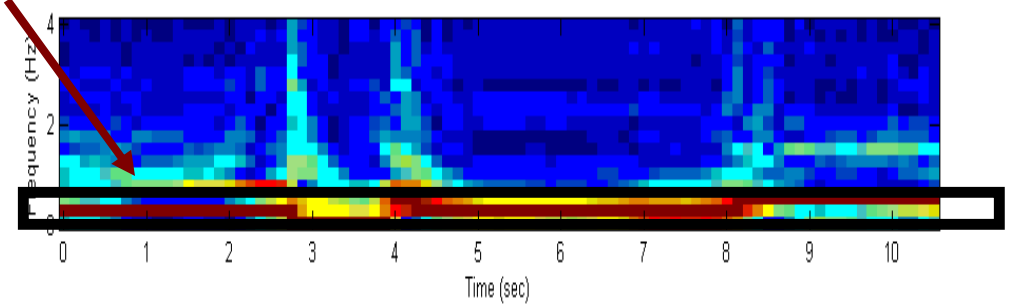


30 MPH Vehicle at 20 meters

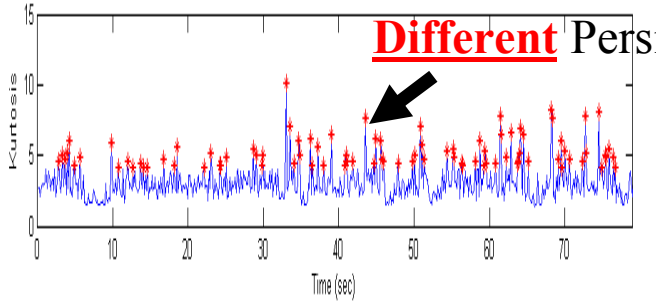


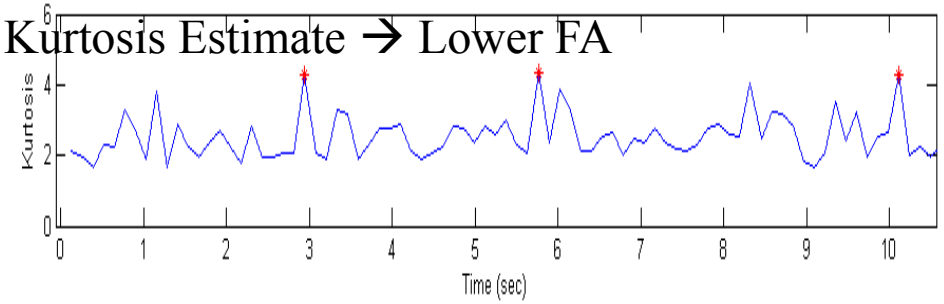
Different Regions : Used for Threshold



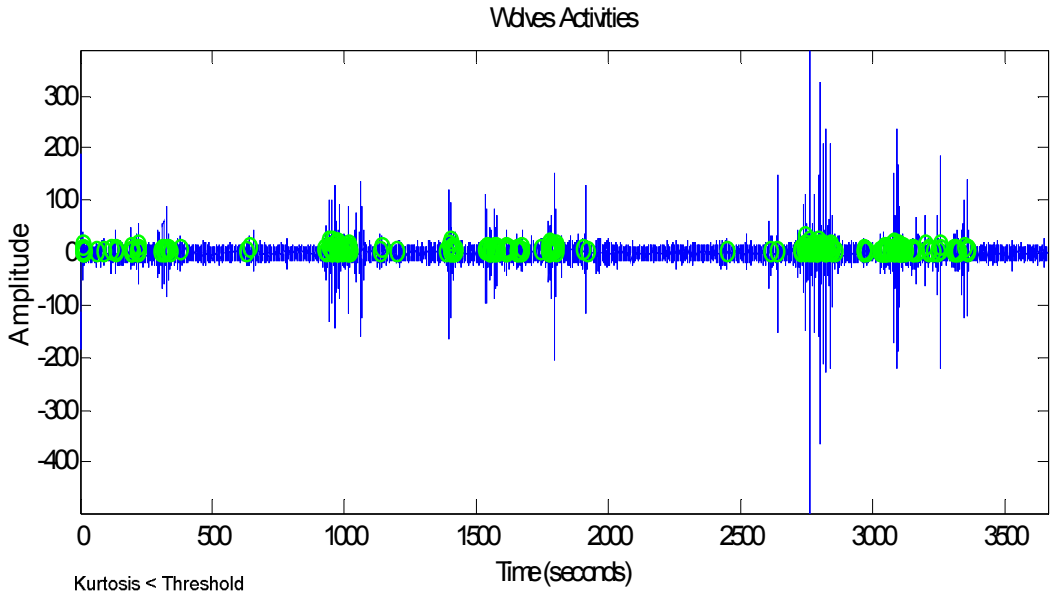


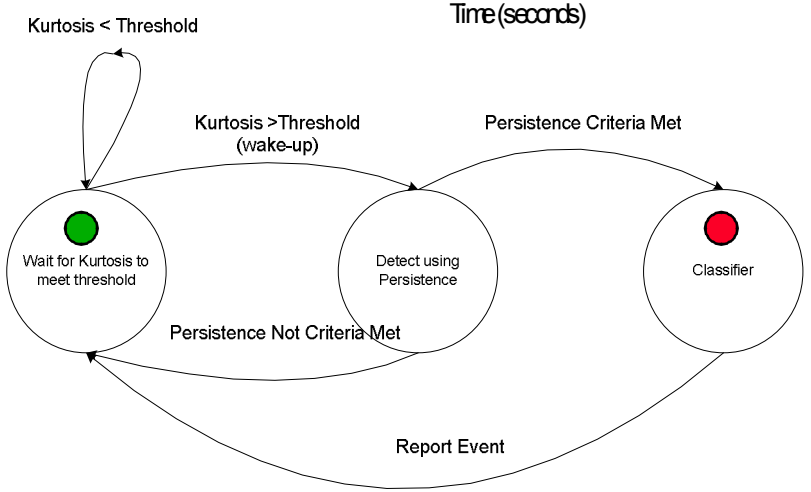
Different Persistent Kurtosis Estimate → Lower FA





Sample Field Test Results – Potential False Alarms (1 Hour) Medium Processing Node





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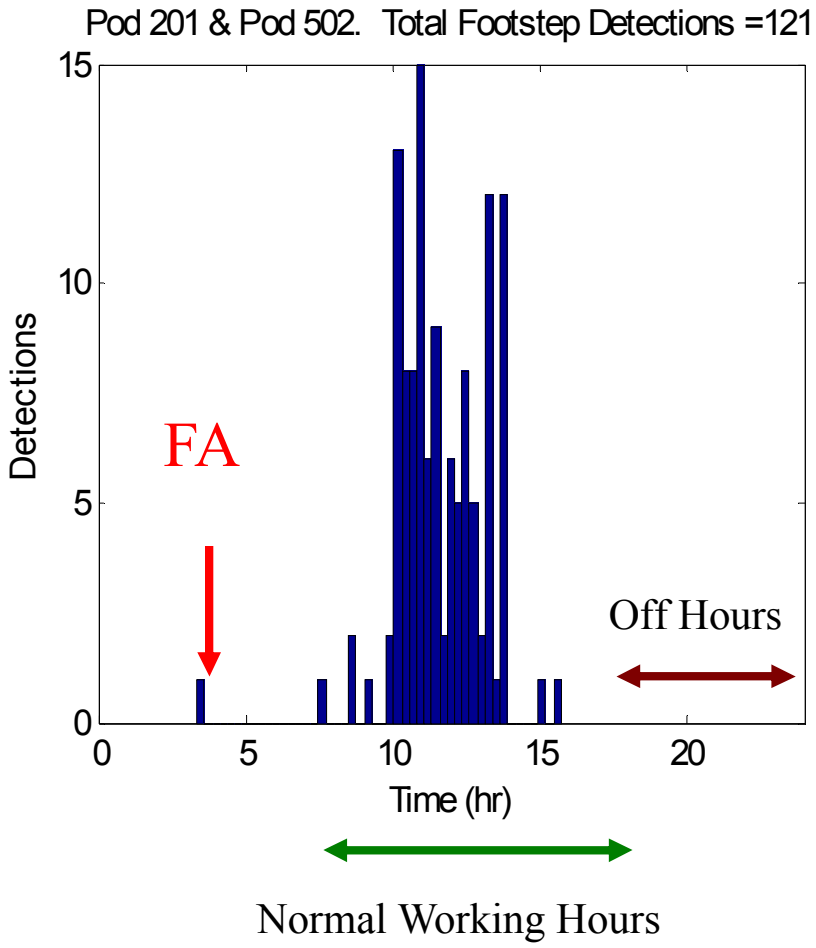
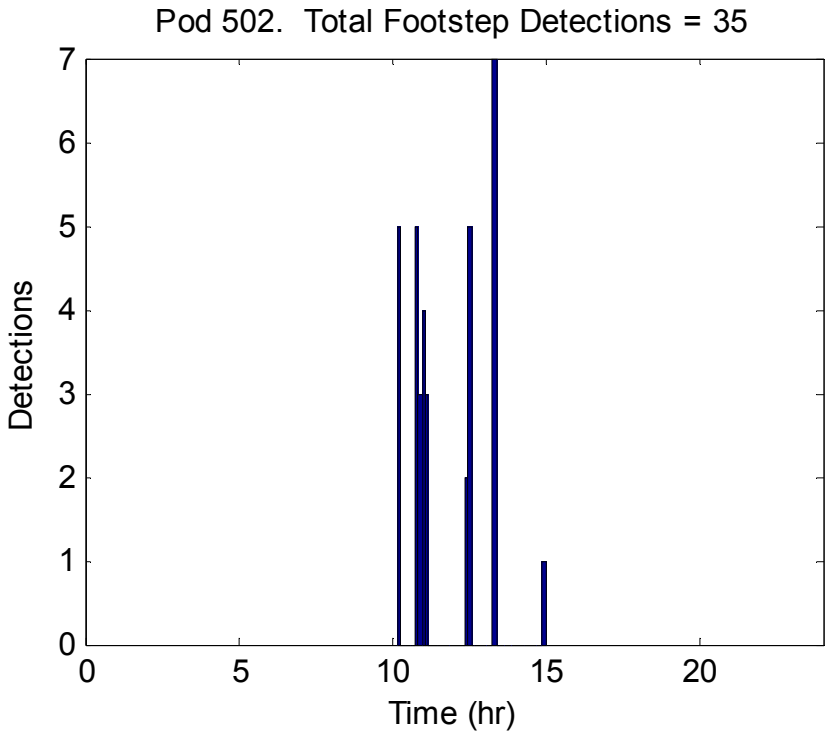
Medium Processing Node Sample Deployment Exercise Results



Controlled Isolated Area



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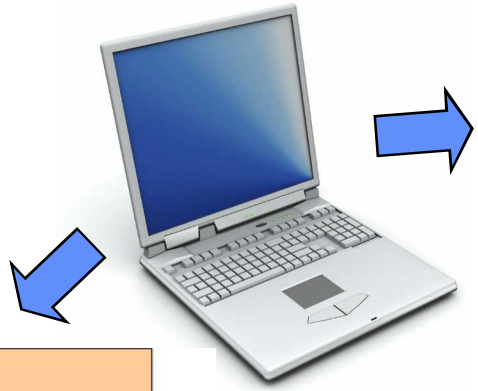
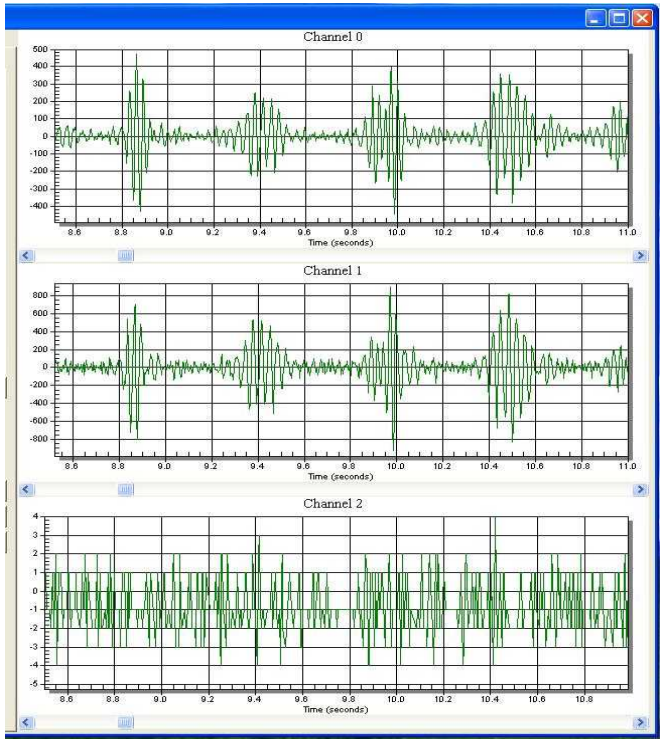
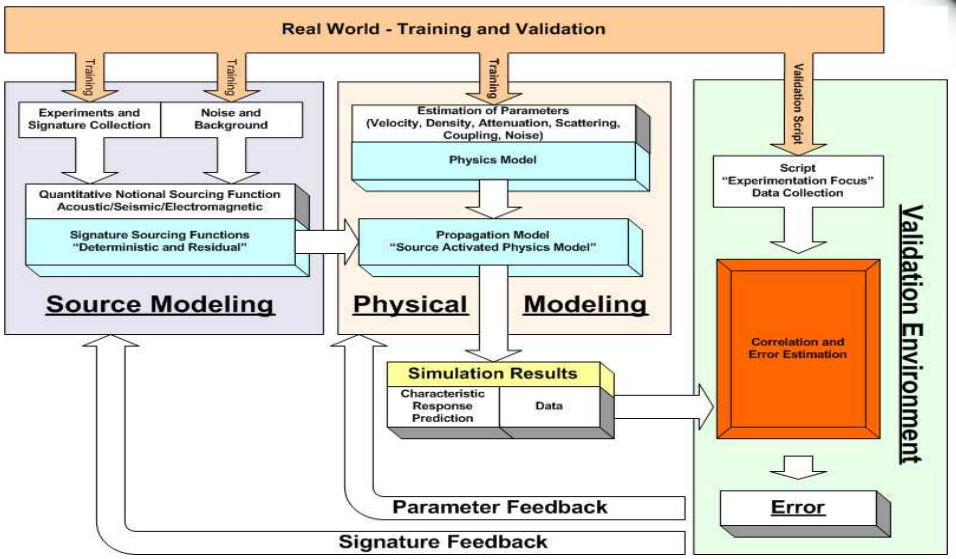
Additional Functionality: Test Bed for data collection and algorithm evaluation

Fly Away Box Functionality

- On-site assessment of the system
- Rapidly gather data for algorithm development and modeling







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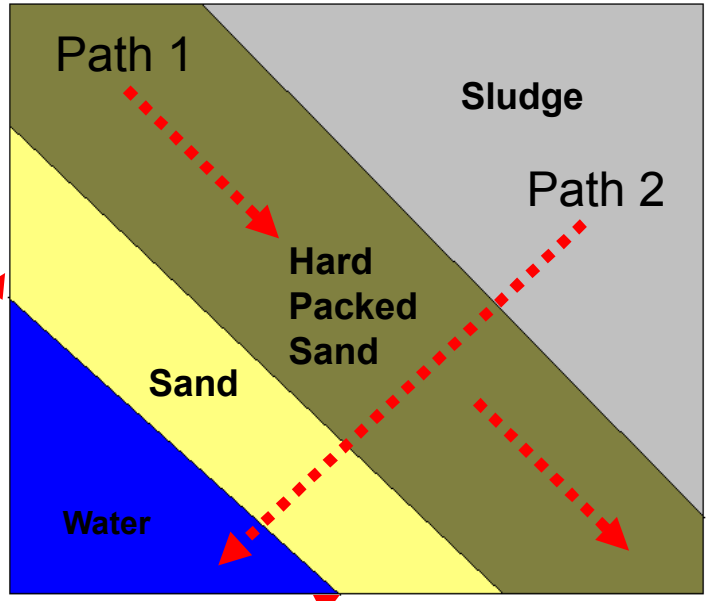
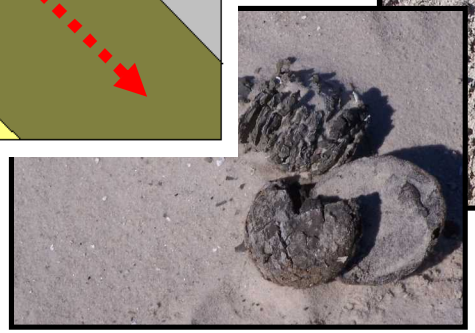
Seismic Boundary Propagation Model

- First Approximation Model Assumptions
  - 400 m x 300 m x 50 m depth
  - Linear Boundary Conditions
  - Approximate wave velocity and densities
    - Used characteristics from similar terrain
    - Can be updated to real numbers by doing field data collection
  - Shoreline water waves not modeled
    - Source Function Needed

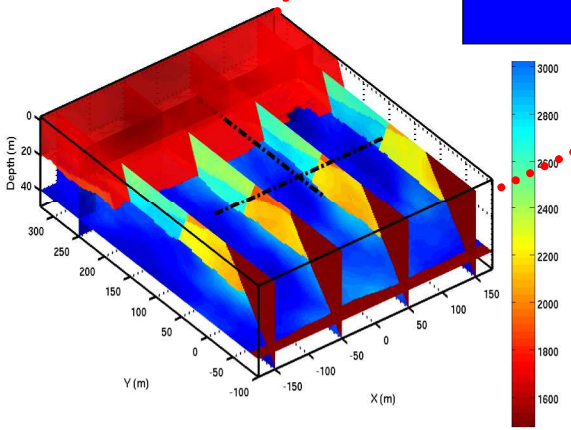


← Sludge

Hard Packed Sand ↕



← Sand



Soil Type	Vp	Vs	Density
Water	1500	0	1000
Sand	2000	1000	1500
Hard Pack	2500	1250	1800
Sludge	800	400	1500

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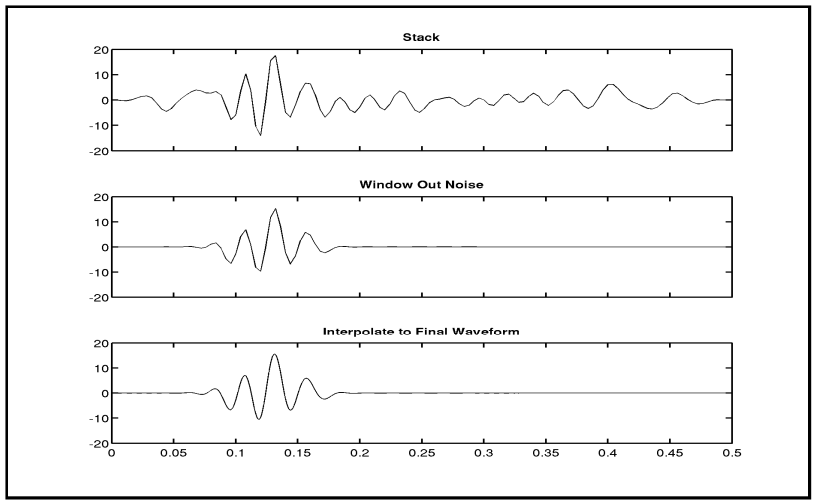
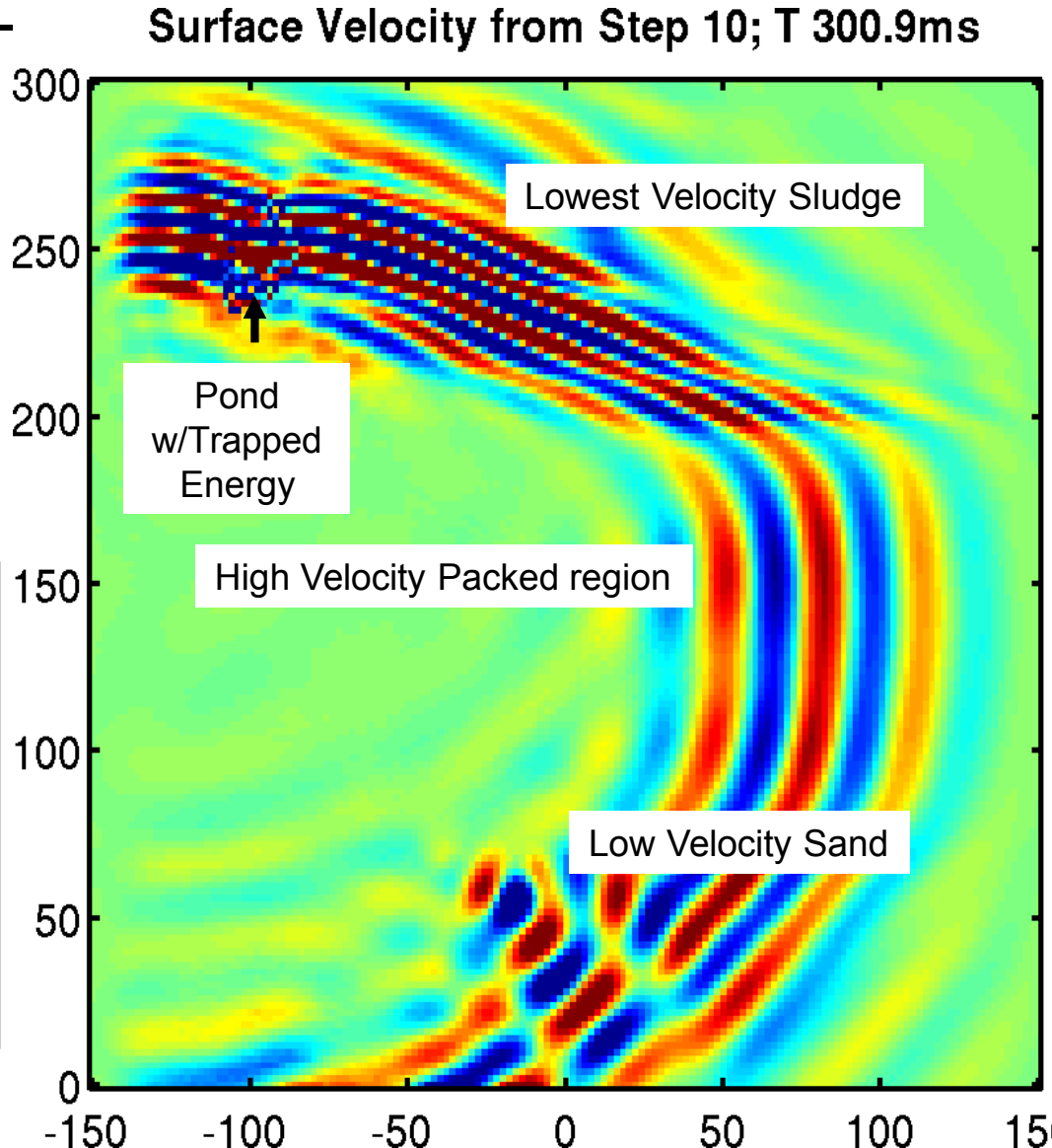
Modeling

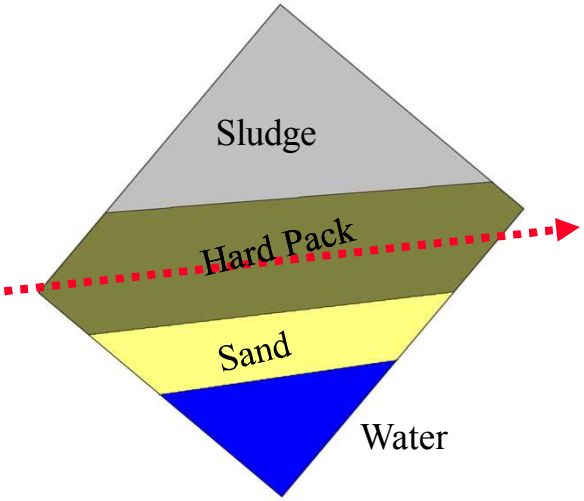
- Each step is modeled individually
  - Reduces length of each run
  - 1m step spacing
- Models are 351×426×103
  - ~15 million nodes
  - 25001 time-steps
- Each run takes ~25 min on 38 nodes
  - Requires 76 processors on Thunderbird
- Data recorded on 151×151 grid of surface receivers
  - We could never collect this volume of data in the real world
  - 87Mb/step at 1ms sample interval

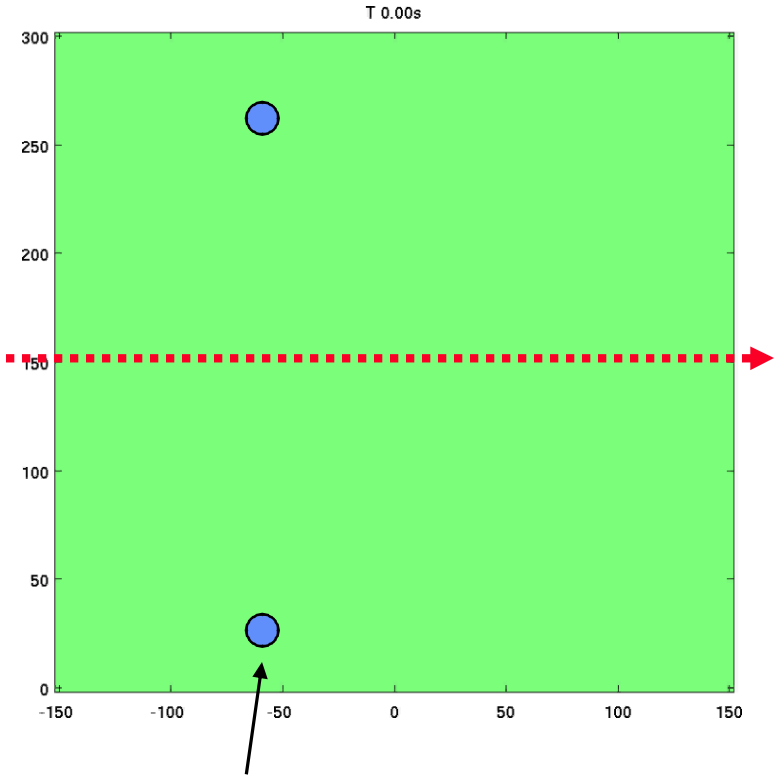




Animation of Model Propagation in Walking path of Line 1

- Each footstep is assigned a random amplitude
- Random offset between steps
- Animation is Path of Line 1
  - Parallel to the shoreline
- High amplitudes in upper left are trapped waves in a small pond





Virtual Sensor Location for Data Gathering and Analysis

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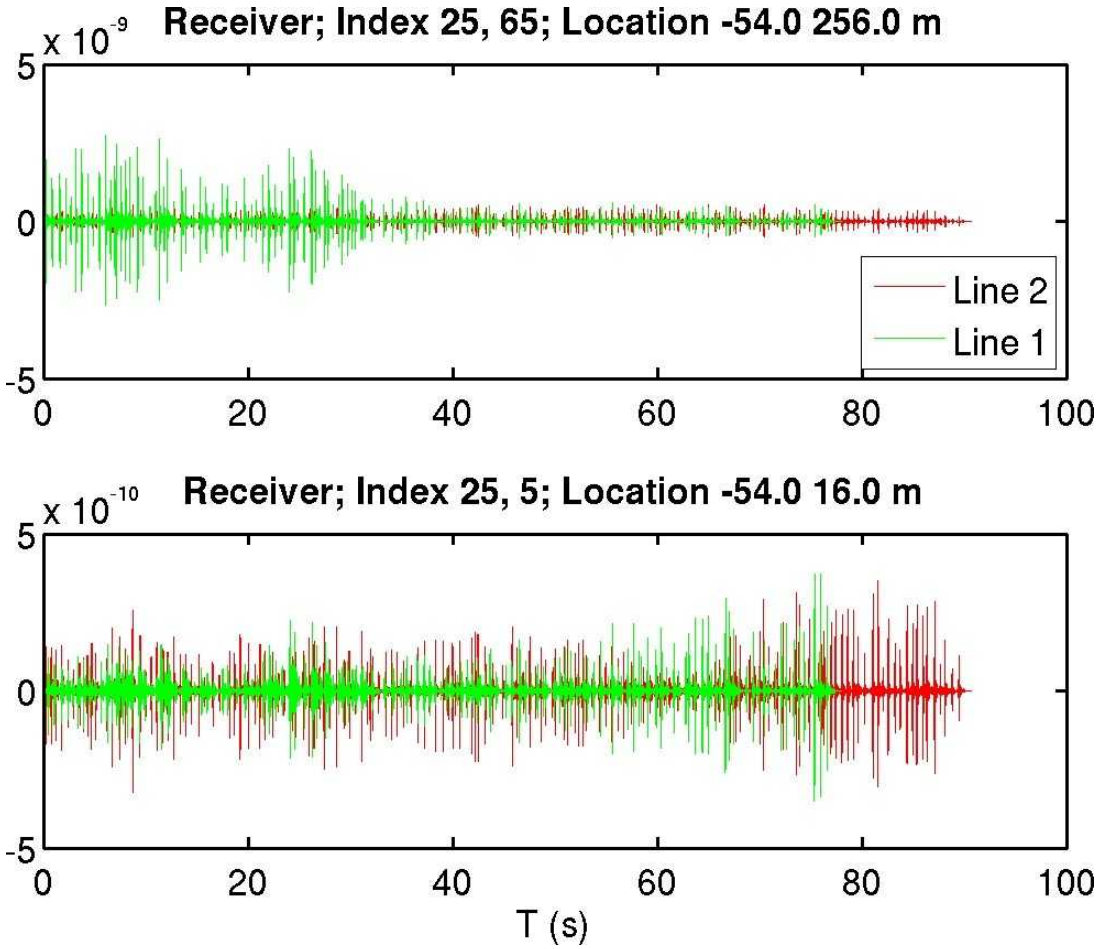
Modeling and Simulation Results



- **Benefits of Modeling**
  - **Place Sensor Nodes and Determine signal content and record data using supercomputer**
  - **Develop algorithms on operational bounds that can be simulated**
  - **Develop false alarm models and mitigation strategies**
  - **Able to predict algorithm and sensor performance if sensor model is known**
    - **Detection and Classification characteristics**

Modeling and simulation is a critical element in system development and mission planning

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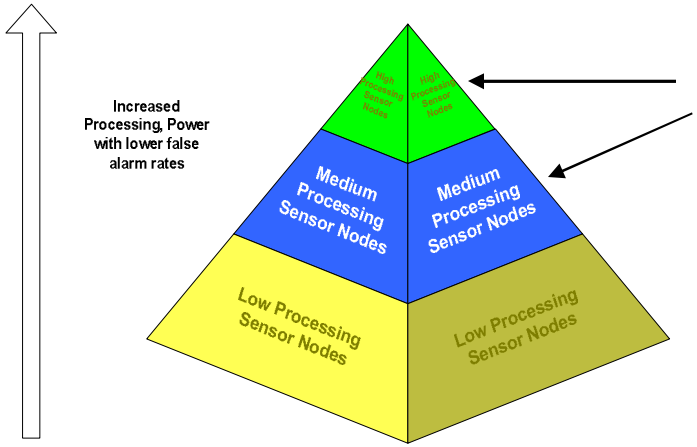
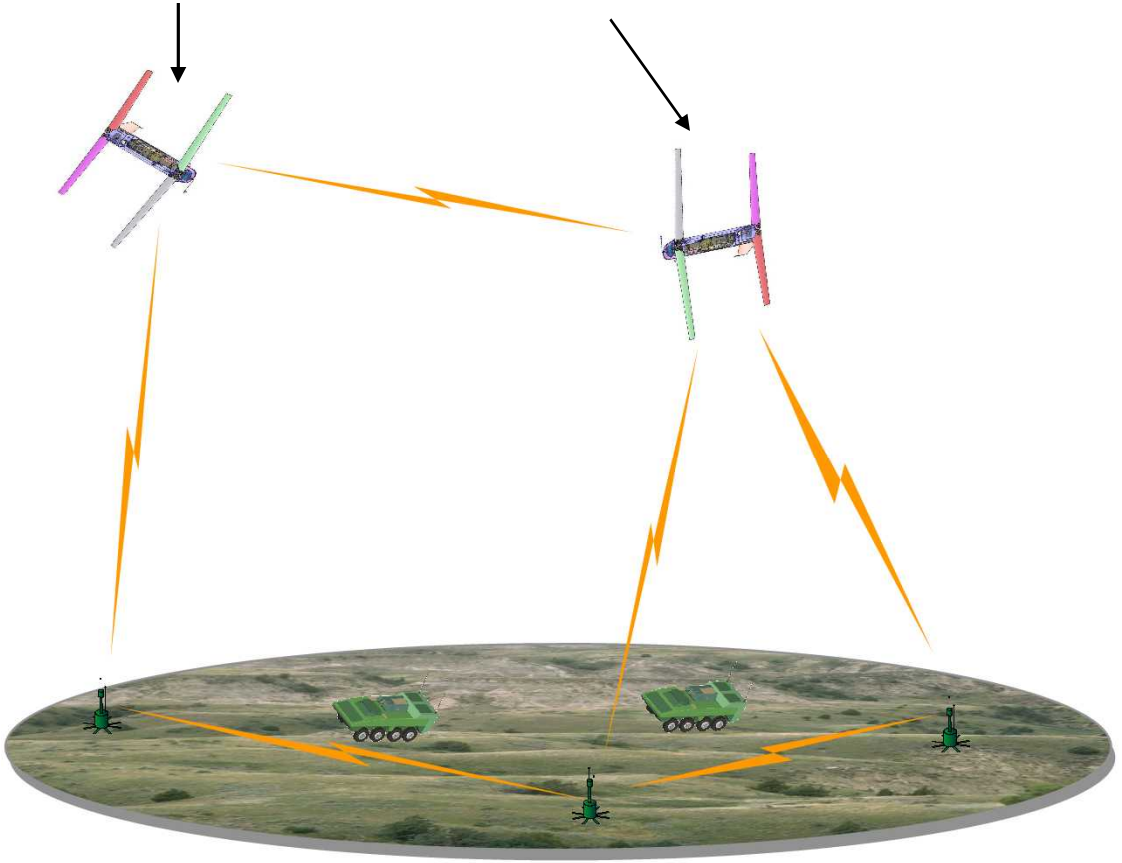
Defense Situational Awareness
Example #2: Adding In Mobile Nodes



Mobile Network Elements



Advancements & Focus

- Data sharing and fusion between UAVs and ground sensors
- Distributed fusion optimized for network performance
  - Dropped Links
- Ad-hoc network for ground and air
  - Optimized Discovery and Recovery

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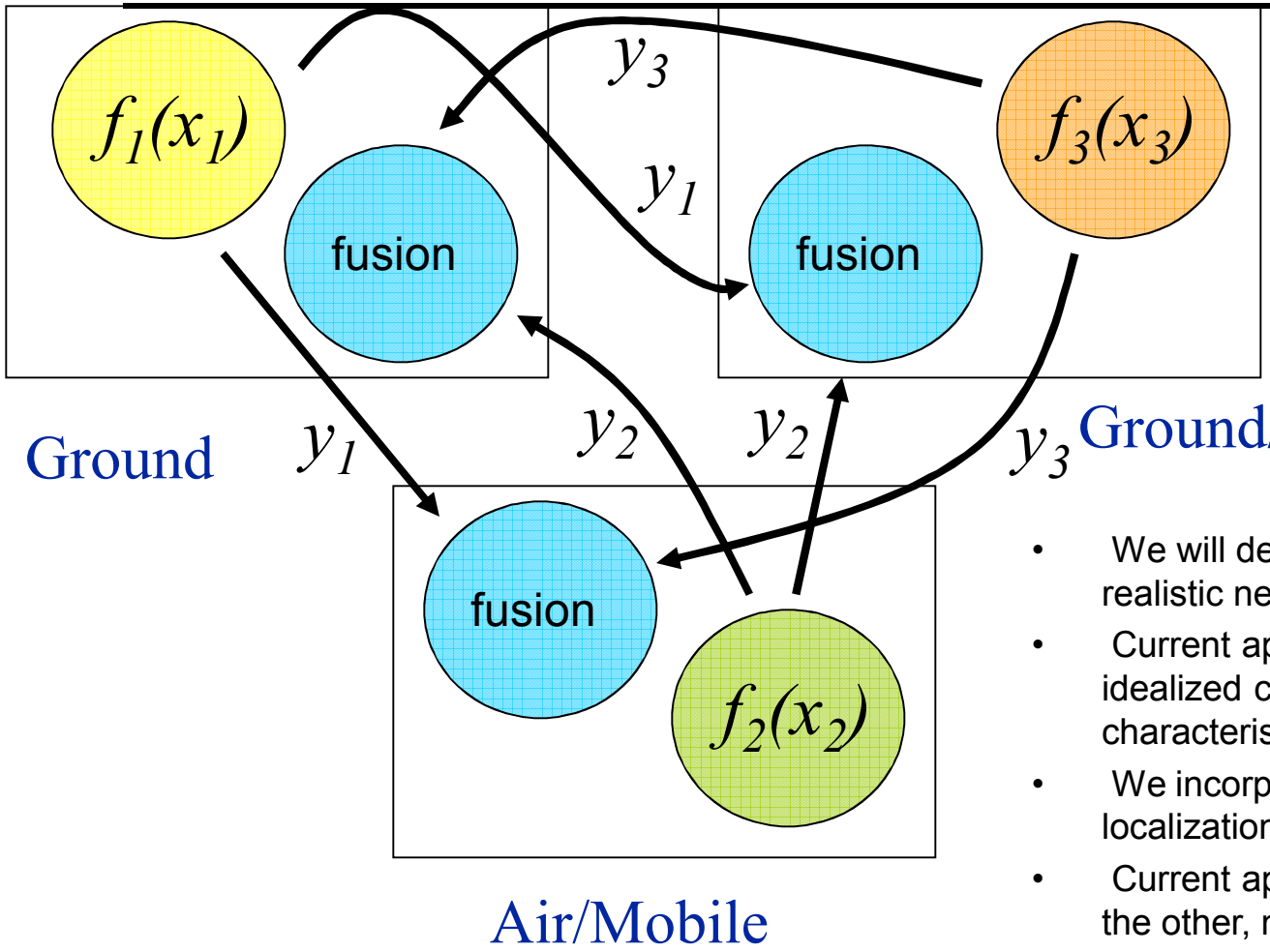
Fusion and Communications Conceptual View



x_i : sensor data

$f()_i$: mapping

y_i : information

- We will determine best *f()* and *y* for realistic network performance
- Current approaches tend to use idealized channel and noise characteristics
- We incorporate both detect/classify and localization/track into fusion
- Current approaches tend to do one or the other, not both

Fusion must tolerate imperfect transmission of information

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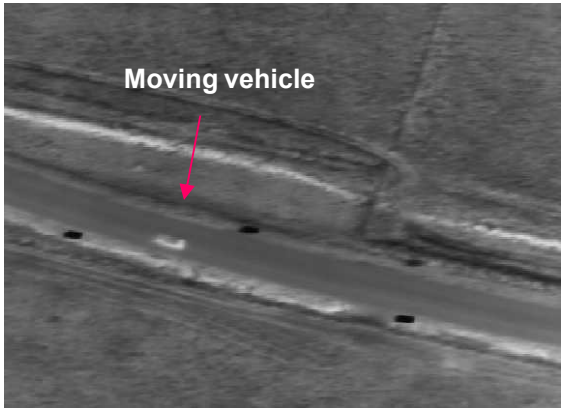
Initial airborne data processing

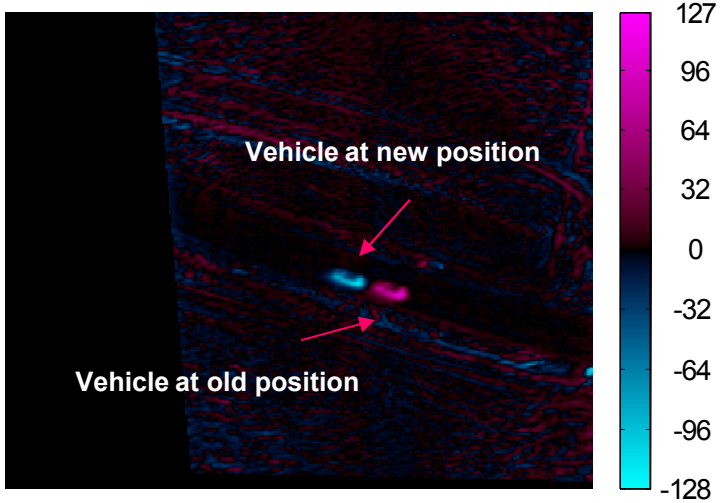
recent frame [59]



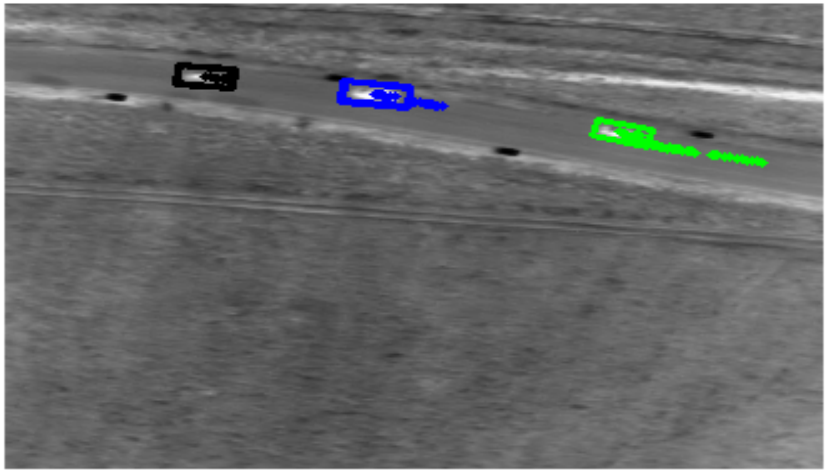
reference frame [73]

- **Detection & Tracking of Moving Targets**
  - **High Processing Node**
- **Different Colors**
  - **Separated Tracks**
- **Tail Length**
  - **Duration of Track**
- **Relative Position**
  - **Translation into GPS**
- **Information Fusion**
  - **Ground Assets**

difference frame 59 to frame 73

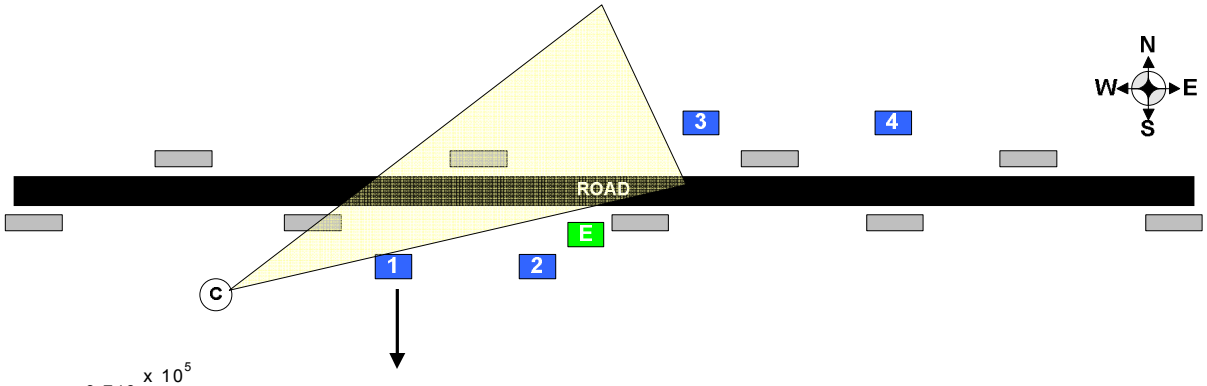


Multi-Target Convoy

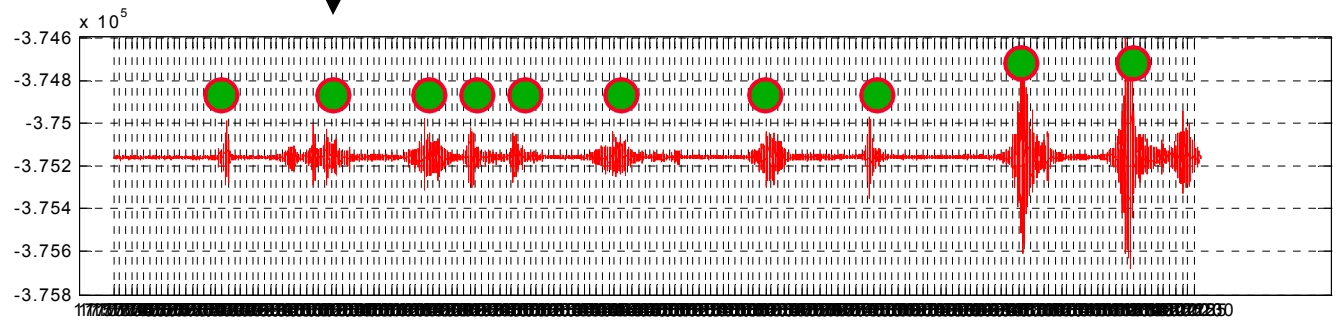


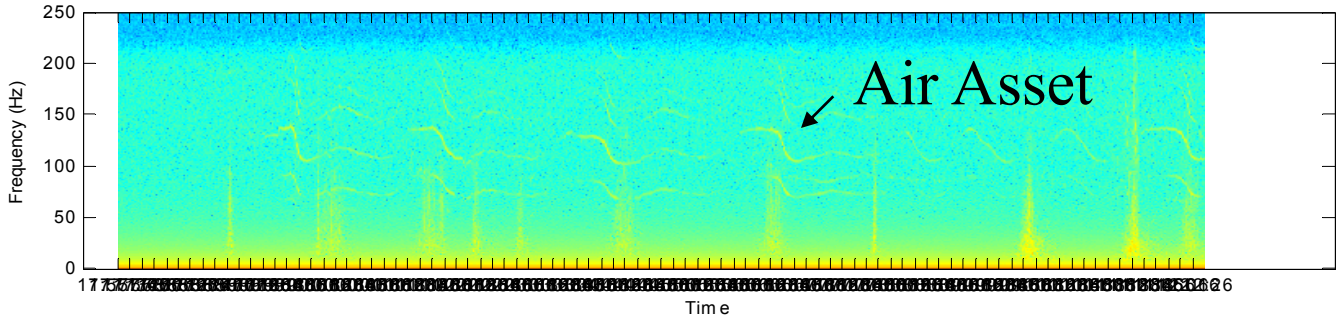
Dr. Mark W. Koch & Dr. Joe Fogler

Initial Ground Data Processing for Data Fusion with Air Data (Sample Seismic Data Set Correlated with Air Data)



* Convoy





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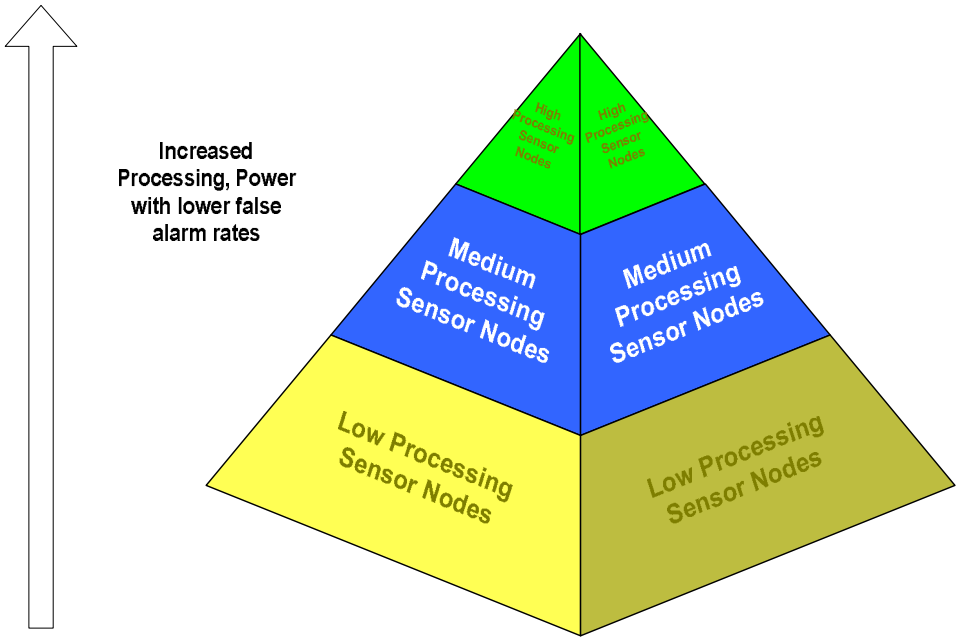
Summary and Conclusions

Layered netted sensor architecture provides performance, flexibility and multifunctionality

- We have discussed layered architecture, platforms, algorithms, networking, modeling and simulation, and mobile platforms
- We have developed a test bed using COTS hardware to address key technical issues and collect real world data



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